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AN ECONOMIC ANALYSIS OF CROP-WATER PRODUCTION FUNCTIONS: CALIFORNIA

by

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ABSTRACT

Water conservation has become an increasingly important issue in much of the arid West and in California in particular. Governmental agencies are interested in instituting policies which will help conserve water (reduce water application levels on a per acre basis). Some of the policies include water pricing, tax credits and/or subsidies for improving field and irrigation delivery efficiencies, reductions in available irrigation water and use of the extension service as a means of conveying water-saving techniques and technologies to farmers.

The effects of the above policies on farmer profits, returns over total variable costs and quantities of water conserved are examined for three crops grown in California - corn, cotton, and processing tomatoes.

The results show that there is potential for conserving water in California through implementation of governmental policies. Water pricing policies could be effective on all crops if the price changes are dramatic rather than marginal. Improvements in field and delivery efficiencies for furrow irrigated crops could conserve water and improve farmers' returns over total variable costs. Improving field efficiencies for sprinkler irrigated crops could conserve some water, but farmers returns over total variable costs are only marginally improved. Reductions in available water will clearly conserve water. The effects on farmer profits, however, vary with the type of crop, type of

irrigation and location of the farm. Using the extension service to encourage farmers to irrigate at profit maximizing levels rather than at the levels currently being used could conserve water and marginally improve profits.

CHAPTER 1

INTRODUCTION

The Water Problem in California

Water is becoming an increasingly important issue in California. It will be the most limiting resource for Californians in the coming decade (Hansen and Wallace, 1978). Development of inexpensive surface water supplies is at an end and the costs of further development may far outweigh the benefits. Californians must decide how to meet the water challenge, reassess their planned water projects and priorities, and if necessary, learn to live with less water.

Both the agricultural and urban sectors of California are competing for presently available water. Some 85 percent of all water used in California is for irrigation. As demand in the other sectors increases and the cost of irrigation rises, the agricultural sector will look for ways to conserve water.

The droughts of 1976 and 1977 point out further conservation needs. During a drought, state law requires that agriculture take cuts in water allotments first (Governor's Office of Emergency Services, CA, 1977).

Seventy-three percent of California cropland and ninety percent of the total value of crops in California are irrigated (Highstreet, Nuckton, and Horner, 1980). A total of 7,802,460 acres receives 29,007,702 acre-feet of water each year (Table 1).

Table 1. Total Irrigated Acreage and Estimated Total Water Applied By Crop in California, 1975.[1/]

Crop	Acreage		Total Water Application	
	Acres	Rank	Acre-Ft.	Rank
Alfalfa Hay	944,979	2	4,494,424.2	1
Barley	616,926	5	1,045,765.4	9
Cotton	908,940	4	3,054,180.0	4
Field Corn	260,857	10	890,399.4	11
Grain Hay	98,875		193,589.0	
Irrigated Pasture	1,025,221	1	4,311,098.4	2
Rice	533,690	6	4,184,788.8	3
Sorghum, Grain	239,938		574,496.0	
Sugar Beets	336,143	8	1,200,061.9	7
Wheat	920,101	3	2,115,726.6	5
Almonds	203,194		607,629.8	
Apricots	18,698		59,735.4	
Grapes	524,420	7	1,706,080.8	6
Lemons	26,869		75,227.6	
Oranges	194,807		616,364.8	
Peaches	65,305		962,405.5	10
Pears	29,531		69,908.3	
Prunes (includes plums)	80,340		267,579.0	
Walnuts	131,263		364,237.4	
Artichokes	10,110		24,264.0	
Asparagus	24,082		48,164.0	
Broccoli	40,742		114,077.6	
Carrots	24,717		63,720.8	
Celery	18,890		45,646.3	
Lettuce	141,757		370,230.8	
Lima Beans	24,443		39,778.7	
Melons	48,308		135,682.9	
Onions	20,854		48,698.8	
Sweet Corn	5,167		19,117.9	
Tomatoes, Fresh	4,313		21,565.0	
Tomatoes, Processing	281,983	9	1,183,057.0	8

[1/] Highstreet et al., 1980, p. 9-10.

The price the farmer pays for this water ranges from \$1.50 to over \$85.00 an acre foot (Table 2). Water costs as a percentage of total variable costs also vary greatly, but are over 20 percent on more than 30 percent of the irrigated land (Table 3).

Solutions to the Water Problem

Many solutions have been offered to California's water problems - water projects, water restrictions, pricing policies, government cost-sharing for investment in water saving technologies, and extension service water conservation programs. State agencies and private interest groups concerned about the water problem in California include the Department of Water Resources, the State Legislature, the Metropolitan Water District, the Sayler Land Co., the League of Women Voters, and the Sierra Club. At the Federal level, some of the agencies interested in conserving water are the General Accounting Office, the Soil Conservation Service, the Bureau of Reclamation, and the U.S. Fish and Wildlife Service.

Objectives

The effectiveness of governmental policies to conserve water depends, in part, on their on-farm profitability, and profits are determined, also in part, by the underlying crop-water production functions. Crop-water production relationships have not been empirically estimated for many crops in California. The estimated production functions can be used as the basis for an economic analysis to assess the effects of

Table 2. Water Cost Range in California and Type of Irrigation, 1975.[1]

Region[2]	Cost		Type of Irrigation by Cost	
	High	Low	High	Low
	$/Acre Foot			
North Coast	$26.95	$ 1.50	G 35 ft.[3]	Stream Diversion
North Bay	51.21	1.50	G 300 ft.	Storage Ponds
South Bay	8.50		G-metered pumps	
Delta	34.92	1.60	G 125 ft.	Diverted
Sacramento Valley	30.00	2.00	G 70 ft.	S State
Mountain Valley	32.76	5.00	G 100 ft. Pac. Gas & Elec.	Stream Diversion
North San Joaquin Basin	41.64	2.50	G 200 ft.	S Local ID
Central Coast	49.08	10.00	G 250 ft.	S Local ID Trans. Charge
San Joaquin Basin	74.52	6.00	G 250 ft.	Ditch Companies
Westside San Joaquin	85.00	8.00	S SWP	S CVP
South Coast	62.00	14.28	S Local ID	G 90 ft.
High Desert	39.36	15.00	G 150 ft.	Stream Diversion
Imperial Valley	40.00	4.75	S SCMWD	S Bureau All American Canal

G = ground water
S = surface water
ID = irrigation district
CVP = Central Valley Project
SWP = State Water Project
SCMWD = Colorado River Water, Southern California Metropolitan Water District

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[1] Highstreet et al., 1980, p. 15-39.

[2] See Figure 1 for map of regions.

[3] Numbers represent lift depth.

Figure 1. Map of Regions and Experimental Sites, California.[1]

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[1] Highstreet et al., 1980, p. 6.

Table 3. Acres Irrigated by Water Cost as Percentage of Total Production Cost in California, 1975.[1]

	Water Cost as % of Total Production Costs			
	0-10%	10-20%	20-30%	30% or more
% of Irrigated Acres in California	35.56	30.96	23.71	10.08

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[1] Highstreet et al., 1980, p. 15-39. Total acres irrigated in 1975 was 7,802,460.

alternative water conservation policies and practices on farm profits, crop output and water use.

This study is part of a larger study to estimate crop-water production functions for key crops in all of the irrigated western United States, and to derive some economic implications from the functions. This study will focus on three key crops in California - corn, cotton, and processing tomatoes. The three crops are among the largest in California in terms of acreage and amount of irrigation water applied (Table 1).

The specific objectives of this study are to:

1. estimate crop-water production functions for corn, cotton, and processing tomatoes grown in selected areas of California;

2. estimate the profit maximizing level of water for each crop under varying water and crop prices;

3. estimate the elasticity of demand for water for each crop with varying crop prices;

4. provide a partial analysis of the effects of the following governmental policies on water application levels, farmer profits, and returns over total variable costs:

   a. water pricing policies;
   b. water quantity restrictions;
   c. changes in irrigation application levels;
   d. programs to improve field and irrigation delivery efficiencies.

CHAPTER 2

LITERATURE REVIEW

Considerable agronomic research focuses on the relationship between crop yield and evapotranspiration (ET). However, it is difficult to make economic recommendations based on an ET-yield function. ET is not an input that has a price and its level is subject to many factors not under the control of the farmer. The rate of ET is determined by water applications, air temperature, humidity, type of crop, soil, and other factors.

Economic analyses of the crop-water relationship have, therefore, been based primarily on yield versus water applied functions. Water is an input which has a price and in irrigated areas can be controlled by the farmer.

Studies based on evapotranspiration are discussed first, followed by a discussion of those economic analyses that have been done on crop-water production functions.

Evapotranspiration Models

Research on the ET-yield relationship has been done by Dudley, Howell and Musgrave (1971), Thornwaite and Holzman (1942), Jensen (1969), Beringer (1961), Fleming (1964), Moore (1961), Cuenca et al. (1978), and Stewart, Hagan and Pruitt (1976, 1977). Plant growth is estimated as a function of plant moisture stress, which is measured by the rate and amount of evaporation from the soil and water surface and transpiration from the plant.

Beringer (1961) developed the Integrated Moisture Stress Index which shows the moisture deficiency experienced by the plant over the entire growing season. Moore (1961) examined the possibility of yield and plant growth being reduced before available soil moisture falls below the permanent wilting point.

Stewart et al. (1976, 1977) studied the relationship between ET and yield for corn, pinto beans, alfalfa, and grain sorghum grown in California. The corn study (1977) was part of a four state study to determine the yield effects of water stress during the three phases of plant growth. The effects on yield of saline water and soil type were also studied.

Cuenca et al. (1978) conducted a study on tomatoes, cotton, gloria pink beans and kidney beans grown in California. They estimated crop-water production functions based on evapotranspiration. They found a linear relationship between yield and ET which agrees with previous findings by Stewart et al. (1977).

Jensen (1969) developed a model to predict the optimum time for the next irrigation based on the soil water depletion rate. Dudley et al. (1971) used a two state variable stochastic dynamic programming model to determine the optimal timing of irrigations over the season in an uncertain environment.

Economic Models

Economic analyses of the crop-water relationship have been presented by Ayer and Hoyt (1981), Delaney et al. (1978), Dyke (1977), Heady and Hexem (1978), Holloway and Stevens (1973), Hogg and Vieth

(1977), Wu, Asce and Liang (1972), and Yaron and Strateener (1973). Yields are estimated as a function of water applied, quality of water applied, and non-water inputs. Regression analysis is used to estimate the production functions which are then used as the basis for the analysis. The marginal value product (MVP) of water is set equal to the price of water and the profit maximizing level of water to apply estimated.

Ayer and Hoyt (1979) did work on cotton, alfalfa, sorghum and wheat grown in Arizona. They estimated production functions, profit maximizing levels of water, elasticities, and returns over total variable costs under varying water conservation policies for Arizona.

Heady and Hexem (1978) also estimated production functions and from these estimated profit maximizing levels of water and fertilizer for corn, cotton, wheat and sugarbeets in Colorado, Texas, Kansas, Arizona, California and Oregon.

Wu et al. (1972) looked at optimizing irrigation costs over the entire growth period by varying the levels of available soil water. Yaron and Strateener (1973) used an integrated systems approach to soil moisture to estimate the crop response function and optimal irrigation policy.

Crop response to water during the various stages of plant growth has recently attracted attention. Studies of the dated crop-water relationship have been presented by Dudley et al. (1971), Flinn and Musgrave (1976), Hall and Butcher (1968), Minhas, Parikh and Srinivansan (1974), and Moore (1961). These studies examined the effects on yield of varying amounts of applied water during each growth stage while keeping seasonal water applied constant.

The dated crop-water production functions have weaknesses. Many of the functions fail to capture the interdependence of growth stages or the riskiness of production. Many do not include factors such as climate, soil or water salinity levels which limits the use of the models to the site on which they were developed.

CHAPTER 3

ECONOMIC THEORY, STATISTICAL METHODS, AND DATA

Theory

Production Function and Farm Profits

The relationship between variable inputs and output of irrigated production is described by a production function. Notationally, the production function can be written as:

$$Y = f\left[(W_1 + W_r)\,\frac{EFF_n}{EFF_o}\,,\ X_2,\ X_3,\ \ldots\ldots\ X_n \,\middle|\, X_n + 1\right]$$

and profits as:

$$\pi = Py\cdot f\left[(W_1 + W_r)\,\frac{EFF_n}{EFF_o}\,,\ X_2 \ldots X_n\right] - \left[\frac{Pw_1}{EFF_c}\,W_1 + Px_2\,X_2 + \ldots Px_n X_n\right] - FC$$

where: π = profits

Y = output

Py = price of Y

W_1 = irrigation water

W_r = rainfall

X_2 to X_n = other inputs

$X_n + 1$ = fixed inputs

EFF_n = field efficiency for which function is being used

EFF_o = field efficiency on which production function is based

Pw_1 = price of irrigation water

Px_i = price of inputs

EFF_c = water conveyance or delivery efficiency

FC = fixed costs

For a production function which includes each growth stage the $\left[(W_1 + W_r)\frac{EFF_n}{EFF_o}\right]$ term is repeated for each stage.

Including preplant irrigation in the equation is a matter of individual choice since a uniform preplant is merely a constant added to the profit maximizing water application level. When rainfall is a large percentage of total water applied, rainfall must be considered a separate variable. Rainfall has no price, but it must be taken into consideration as profit maximizing irrigation water levels are determined because it too contributes to yield.

Differentiation of the profit function results in the following system of equations which can be solved simultaneously to determine the profit maximizing level of inputs:

$$\frac{\partial \pi}{\partial W_1} = Py \frac{\partial Y}{\partial W_1} - Pw_1 = 0$$

$$\frac{\partial \pi}{\partial X_2} = Py \frac{\partial Y}{\partial X_2} - Px_2 = 0$$

$$\vdots$$

$$\frac{\partial \pi}{\partial X_n} = Py \frac{\partial Y}{\partial X_n} - Px_n = 0$$

In order to ensure a maximum, the sufficient condition for profit maximization must also be met: the second derivative of the profit function must be negative.

The profit maximizing level of input differs from that which maximizes yield. Estimation of the yield maximizing level of input does not include prices. The yield maximizing level can be found by setting $\frac{\partial y}{\partial W_1}$ equal to zero. The yield maximizing level of input will always be greater than the profit maximizing level unless the price of the input is zero. At a zero price both levels will be equal.

Field Efficiency

Irrigation efficiency is defined as the ratio of water stored in the root zone to water delivered to the field. The equation given by Israelsen and Hansen (1962, p. 289) for water-application efficiency is used to estimate field efficiency:

$$EFF = \frac{100\ W_f - (R_f + D_f)}{W_f}$$

where: EFF = water-application or field efficiency

W_f = water delivered to field

R_f = surface runoff from field

D_f = deep percolation below field root-zone soil.

Changes in field efficiency can affect profits in two ways. Field efficiency affects the level of water to be applied, thereby affecting one variable cost. Field efficiency also affects yield and therefore revenues.

Each crop-water production function estimated in this research has a particular field efficiency associated with it. If a farmer has a field efficiency equal to that associated with the production function no adjustments in water application levels need be made. If the efficiencies differ then more or less water will need to be applied to account for the difference. The following equation can be used to adjust for varying efficiencies:

$$W_n = W_o \frac{EFF_o}{EFF_n}$$

where: W_n = level of water with new efficiency

W_o = level of water with original efficiency

EFF_o = original efficiency

EFF_n = new efficiency.

If a production function is based on a field efficiency of say 80%, then as varying field efficiencies are included in the production function one water application level will have varying yield levels associated with it (Figure 2). Each of the functions graphed in Figure 2 has a different profit maximizing water application level and yield. Each has the same yield maximum, but this is achieved with greatly varying water application levels.

The crop-water production function for a given crop based on a particular field efficiency can be modified for use in areas with different field efficiencies. As shown in Figure 2, the profit maximizing water application level has almost doubled when the field efficiency is cut in half and the yield has decreased. This will lead to higher variable costs and lower revenues for the farmer with the low field efficiency.

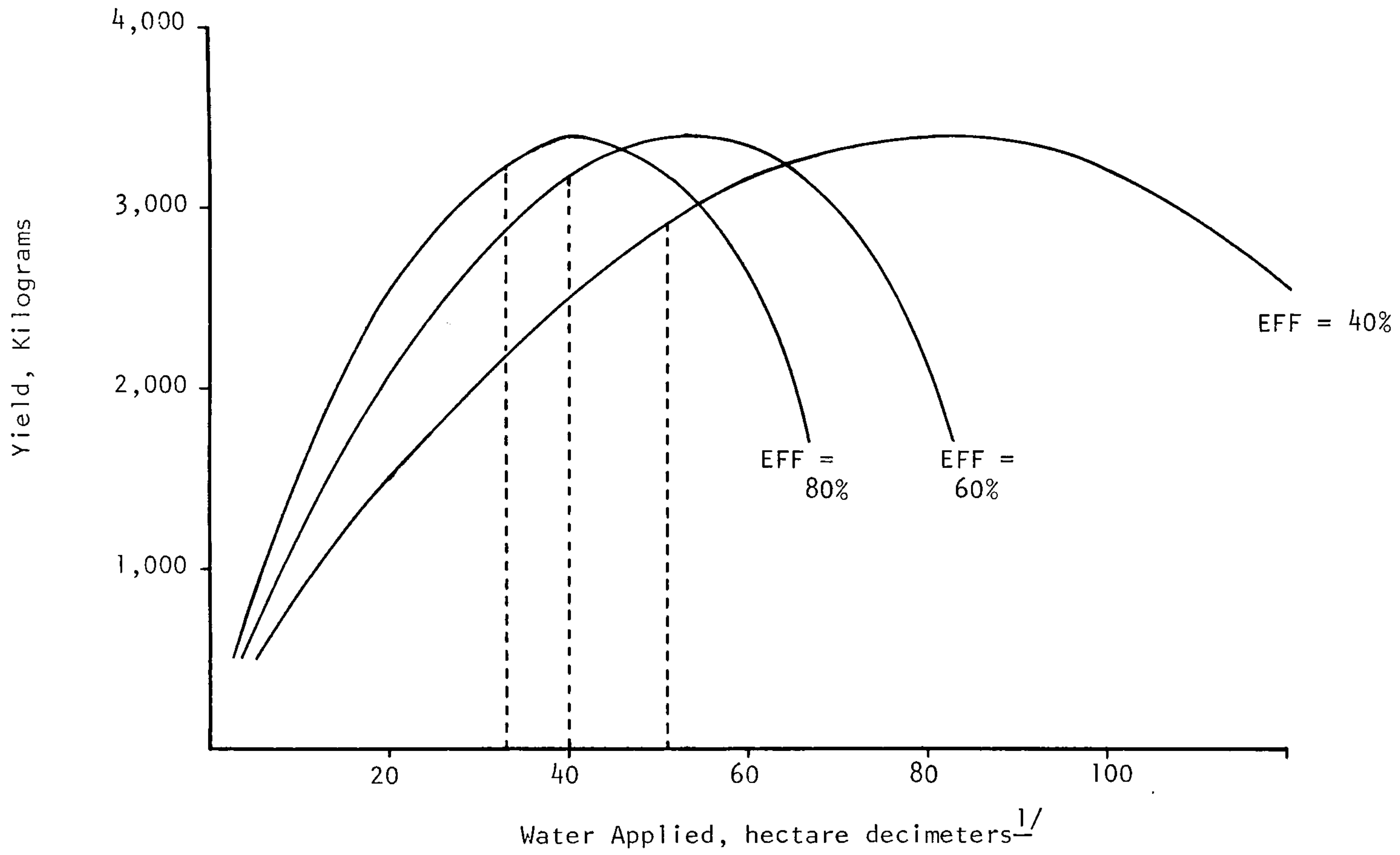

Figure 2. Crop Water Production Function with Varying Field Efficiencies.

1/ Dotted lines represent profit maximizing level of water to be applied with each field efficiency.

Delivery Efficiency

Delivery efficiency can also affect profits. Delivery efficiency is the ratio of the amount of water that reaches the field to the amount of water that is diverted or pumped. Delivery efficiency can be calculated using the Israelsen and Hansen (1962, p. 288) definition of water-conveyance efficiency:

$$E_c = 100 \frac{W_f}{W_R}$$

where: E_c = water-conveyance or delivery efficiency

W_f = water delivered to field

W_R = water diverted or pumped.

Delivery efficiency affects the price of water at the field. Low delivery efficiencies mean higher water costs for farmers. The effect of delivery efficiency on profits can be calculated. Water costs are based on the profit maximizing level of water divided by the delivery efficiency. Yield and revenue are calculated using the amount of water reaching the field and costs are calculated using the amount of water diverted or pumped in conjunction with the above formula for water conveyance efficiency.

Elasticity of Demand

The price elasticity of demand is the percentage change in the quantity of an input demanded given a one percent change in its price and can be derived from the demand function. The demand function for an input indicates the amount of input which will be demanded at each input price. Demand for an input in a production process can be estimated from the production function and input and output prices.

Mathematically the elasticity of demand for W_1, water at the field, given a field efficiency, is:

$$\varepsilon_d W_1 = \frac{\partial W_1}{\partial Pw_1} \; \frac{Pw_1}{W_1} .$$

If elasticity is greater than $|-1|$ the demand for that input is said to be elastic; the percentage change in quantity demanded is greater than the percentage change in price. If the elasticity is less than $|-1|$ demand is inelastic and the percentage change in quantity demanded is less than the percentage change in price. If the elasticity equals $|-1|$ demand is unit elastic and the percentage change in quantity demanded equals the percentage change in price.

Statistical Methods

The statistical technique used to estimate the production functions is ordinary least squares regression analysis. Adjusted coefficients of determination, $\bar{R}^2$, and t statistics are given to show the statistical reliability of the estimated regression line.

Data

To statistically estimate a crop-water production function which shows both the profit and yield maximizing levels of water, agronomic experiments must include a range of irrigation treatments from yield maximizing or greater to levels which cut plant growth. Experimental data which stressed the crop were found for corn, cotton, and processing tomatoes. No other adequate experimental data were found.

The crop-water production functions were estimated using water application levels and not evapotranspiration (ET). Water applied is used because water is an input in the production process and must be purchased. Water is an input which can be measured and choosing the level of water to apply is a major decision for farmers. A discussion of the experiments, and especially the experimental design for each crop, follows.

Corn

The corn data are taken from "Optimizing Crop Production Through Control of Water Salinity Levels in the Soil" by Stewart et al. (1977) of the University of California at Davis. The experiment was part of a four state project to study the effects of various water and salinity levels on plant growth.

The experimental site was at Davis, California. Data were recorded for 1974 and 1975. The experiments were a "line source" continuous variable design. A single line source sprinkler was used which gives a linearly decreasing amount of water applied as one moves away from the line. All plots were sprinkler irrigated with a few plots receiving simulated year 2000 Colorado River water (salt content 1350 ppm), the rest receiving "normal Davis water". Four time schedules were used for irrigation. One schedule had all growth stages receiving varying levels of irrigation. The three other schedules consisted of suspension of irrigation for whole growth stages (vegetative and pollination) while varying the levels of water received in the other stages.

All plots were irrigated during the maturation stage at varying levels. The water application levels ranged from 0 hectare decimeters to 6.06 hectare decimeters (23.86 acre inches). All plots were brought to field capacity before planting.

The soil at the site is Yolo silt loam. Part of the plots had salinized soil. All plots in both years received the same amount of fertilizer, 225 kg/ha. of nitrogen, 85 kg/ha. of phosphorous (P_2O_5), and 112 kg/ha. of potassium (K_2O) in a 16-6-8 mix which also contained zinc. Planting dates were May 16, 1974 and May 14, 1975. Harvesting dates were September 12, and September 10 for 1974 and 1975 respectively. Pan evaporation for each of the seasons was 11.52 dm. and 10.56 dm. Funks 4444 variety of corn was used. Field efficiency for the experimental field was .95.

Rainfall during the summer growing season at Davis is generally very light (approximately .48 dm. or 1.9 inches). Farmers in the area plan on irrigating throughout the season and expect no rain. Winter rains and snow are expected to fill the soil profile, but if inadequate, many farmers irrigate to fill the soil profile before planting.

Cotton

Two varieties of cotton are analyzed, Acala SJ-1 and Acala SJ-2. The SJ-1 cotton data are from a study by Heady and Hexem (1978) from experiments in 1967, 1968, and 1969 at Shafter and West Side, California. Each site is treated separately. The SJ-2 cotton data are from a study conducted by Cuenca (1980) at West Side in 1977.

The Acala SJ-1 cotton experiments at Shafter for 1967 and 1968 were a central composite rotatable design. The 1969 experiment was an incomplete block design with factorials. All experimental plots in all years were gravity irrigated. Irrigations were scheduled whenever soil moisture tension reached a predetermined level. Thirteen water and fertilizer treatment combinations were randomly applied to the plots in each block. The water application levels ranged from 2.54 ha.dm. to 10.16 ha.dm. (10 acre inches to 40 acre inches). All plots were brought to field capacity before planting. The fertilizer treatments were applied as a side dressing in late May and ranged from 0 kg/ha. to 280 kg/ha. of nitrogen.

The soil at Shafter is Hesperia sandy loam. Planting dates were May 3, April 15, and April 1, for 1967, 1968 and 1969 respectively. Two harvests were recorded for each year: October 17 and November 14 in 1967, October 24 and November 29 in 1968, and October 22 and November 13 in 1969. Pan evaporation for each of the three seasons was 14.5 dm., 16.7 dm., and 17.3 dm. The field efficiency for this experimental field was .75.

The Acala SJ-1 cotton experiments at West Side in 1967 and 1969 were similar to those conducted at Shafter. Only 1967 and 1969 data were used from West Side because a plant spacing variable was included in the 1968 experiment. In 1967 the design was a central composite rotatable and in 1969 was an incomplete block design with factorials. The type of irrigation and the scheduling were the same as at Shafter.

The water application levels ranged from 0 ha.dm. to 8.89 ha.dm. (0 to 35 acre inches). Nitrogen fertilizer was again applied as a side-dressing in late May ranging from 0 kg/ha. to 392 kg/ha. All plots were brought to field capacity before planting.

The soil at West Side is Panoche clay loam. Planting dates were April 20 and April 12 for 1967 and 1969 respectively. The two harvesting dates for each year were November 3 and December 6 for 1967 and October 29 and November 25 for 1969. Pan evaporation for 1967 was 16.15 dm. and for 1969 17.12 dm. The field efficiency for both years was .75.

The Acala SJ-2 cotton experiment was at West Side in 1977. The "line source" continuous variable design was used. All plots were sprinkler irrigated and brought to field capacity before planting. The irrigation levels were linearly varied throughout the growing season. The application levels ranged from .67 dm. to 6.3 dm. (2.64 to 24.8 inches). All plots received the same amount of nitrogen fertilizer. The planting date was April 22 and harvesting dates were September 22, October 21 and November 10. The field efficiency for this experiment was .95.

Both Shafter and West Side have little or no rainfall during the cotton growing season. Cotton production is totally dependent on irrigation.

Tomatoes

The tomato data are taken from an experiment conducted by Cuenca et al. (1978) at Davis, California in 1977. The UC-82 variety was used. The "line source" continuous variable design was used with single row spacing. All plots were sprinkler irrigated at a fixed frequency- once a week. Seasonal irrigation levels ranged from .31 dm. to 4.18 dm. (1.2 acre inches to 16.46 acre inches). The soil at Davis is Yolo silt loam. All plots received the same amount of fertilizer, 90 kg/ha. of nitrogen and 22 kg/ha. of phosphorous combined pre-planting levels and those added as a side dressing at the time of thinning. The planting date was April 20 and the harvest date was September 6. The field efficiency was .95. As noted earlier the rainfall at Davis is minimal during the growing season.

Prices

Water prices are taken from "Agricultural Water Use and Costs in California" (Highstreet et al., 1980). A low, medium and high price is used for each crop based on the range of prices presented in Table 2. The prices used for water are \$4.86, \$24.32 and \$48.64 an hectare decimeter. The prices represent estimates of current (1981) charges. These prices correspond to \$.50, \$2.50 and \$5.00 an acre inch respectively.

Product prices are taken from the Wall Street Journal (April, 1981) and the journal of Agricultural Statistics 1980.

Current prices (April, 1981) and the high and low prices over the past ten years are used in the analysis of corn and cotton. Corn prices are \$88, \$110 and \$154 per metric ton. Cotton prices, the price of lint plus seed per kilogram of lint are \$1.34, \$1.76 and \$2.13 per kilogram. There are 1.64 kilograms of cotton seed per kilogram of lint. Prices for cotton seed are \$.08, \$.10 and \$.13 per kilogram. The price of the seed is multiplied by 1.64 and added to the price of lint per kilogram resulting in the above prices of \$1.34, \$1.76 and \$2.13 per kilogram.

One tomato price is used, \$64/metric ton. The price is from the *Wall Street Journal*, April 1981.

Total variable costs are calculated from 1981 California crop data (Horner, 1981). The costs include the costs of fertilizer, seed, pesticides, herbicides, fuel, labor and harvest costs.

CHAPTER 4

STATISTICAL RESULTS

Production functions for corn, cotton, and processing tomatoes are given in Table 4. Two functions are shown for corn, one with irrigation water and rainfall broken into three growth stages, the other with irrigation and rainfall for the season. Cotton and tomato functions are for total water over the growing season - preplant, irrigation, and rainfall.

The functions in Table 4 represent the "best" functions in terms of goodness of fit, sign and significance of coefficients, and in making agronomic and economic sense from among the many functions estimated and evaluated.

Corn

The growth stage production function for corn explains 84% of the variation in yield ($\bar{R}^2 = .84$). The quadratic function includes variables for water applied in the first and the last stages of plant growth and seasonal water applied. The combination of separate growth stage variables with a total seasonal water variable was chosen because it accounts for the interaction of water among the growth stages. The amount of water applied in one stage affects the impact that water applied in a later stage can have on yield. Pan evaporation accounts for variations in weather in the two years of the experiments.

Table 4. Crop-Water Production Functions, Field Corn, Cotton, Processing Tomatoes, California.

Corn

Growth Stages - Davis

$$Y_F = \overset{***}{16.04372} - \overset{**}{1.02138}V - \overset{***}{1.23116}M + \overset{***}{2.48777}\,(V + P + M)$$

$$-\overset{***}{.30309}V^2 - \overset{***}{.74174}P^2 - \overset{***}{.28248}M^2 - \overset{***}{.76277}\mathrm{TPE}$$

$$-\overset{***}{1.59648}\mathrm{DUM1} - \overset{***}{.47830}\mathrm{DUM2}$$

$\bar{R}^2 = .84$ $F = 130.335$

Total Water - Davis

$$Y_F = \overset{***}{17.98176} + \overset{***}{1.48324}\mathrm{TW} - \overset{***}{.14168}\mathrm{TW}^2 - \overset{***}{.94082}\mathrm{TPE}$$

$$-\overset{***}{1.79824}\mathrm{DUM1} - \overset{***}{.33223}\mathrm{DUM2}$$

$\bar{R}^2 = .74$ $F = 122.903$

Cotton

Shafter - Acala SJ-1

$$Y_C = \overset{***}{-1102.74} + \overset{***}{351.21}W - \overset{***}{19.14}W^2 + \overset{***}{1.19}N - \overset{***}{.00327}N^2$$

$$+ \overset{**}{34.67}\ \mathrm{TPE}$$

$\bar{R}^2 = .69$ $F = 33.368$

West Side - Acala SJ-1

$$Y_C = \overset{***}{4406.63} + \overset{***}{295.93}W - \overset{***}{17.11}W^2 + \overset{***}{2.13}N - \overset{***}{.00395}N^2 - \overset{***}{270.51}\mathrm{TPE}$$

$\bar{R}^2 = .89$ $F = 84.94$

West Side - Acala SJ-2

$$Y_C = \overset{***}{393.41} + \overset{***}{562.82}W - \overset{***}{54.419}W^2$$

$\bar{R}^2 = .97$ $F = 316.539$

Table 4--Continued

Processing Tomatoes

Davis - UC-82

$$Y_T = \overset{***}{28.447} + \overset{***}{5.082}W$$

$\bar{r}^2 = .69$ F = 97.718

Y_F = grain yield of corn in metric tons per hectare

Y_C = cotton yield in kilograms of lint per hectare

Y_T = tomato yield in metric tons per hectare

V = irrigation water applied and rainfall during vegetative phase in hectare decimeters

P = irrigation water applied and rainfall during pollination phase in hectare decimeters

M = irrigation water applied and rainfall during maturation phase in hectare decimeters

TW = irrigation water applied and rainfall, post preplant to harvest in hectare decimeters

W = irrigation water applied including preplant irrigation and rainfall in hectare decimeters

N = nitrogen applied in kilograms per hectare

TPE = total pan evaporation for the season in decimeters

DUM1 = salinity of soil, 0 if electrical conductivity of saturation extract (EC_e) ≤ 5, 1 if $EC_e > 5$

DUM2 = salinity of water, 0 if salts $\leq$ 1350 PPM, 1 if salts > 1350 PPM

*** = coefficient is statistically significant at the 1% level

** = coefficient is statistically significant at the 5% level

"Dummy" variables are used to differentiate between plots which had saline soil and those which did not, and between plots which received saline irrigations and those which did not. All coefficients have the expected sign and all are significant at the 1% level except water applied in the vegetative phase (V) which is significant at the 5% level (two tail test). The negative effects of saline soil and water are indicated by the negative signs on the "dummy" variables.

The total water applied production function for corn (Figure 3) explains 74% of the variation in yield ($\bar{R}^2 = .74$). A pan evaporation variable and two "dummy" variables, one for plots which received saline water and for plots which had saline soil, are included. All the coefficients have the expected signs and are significant at the 1% level. The saline "dummy" variables again have a negative sign. The total water applied equation does not have as "good" a fit as the growth stage equation.

Cotton

The quadratic production function for Acala SJ-1 cotton at the Shafter (Figure 4a) site explains 69% of the variation in yield ($\bar{R}^2 = .69$). Pan evaporation is included to account for variations in yield due to differences in weather over the three year period in which the experiments were conducted. All the coefficients have the expected sign and are significant at the 1% level except for the nitrogen squared term which is significant at the 5% level.

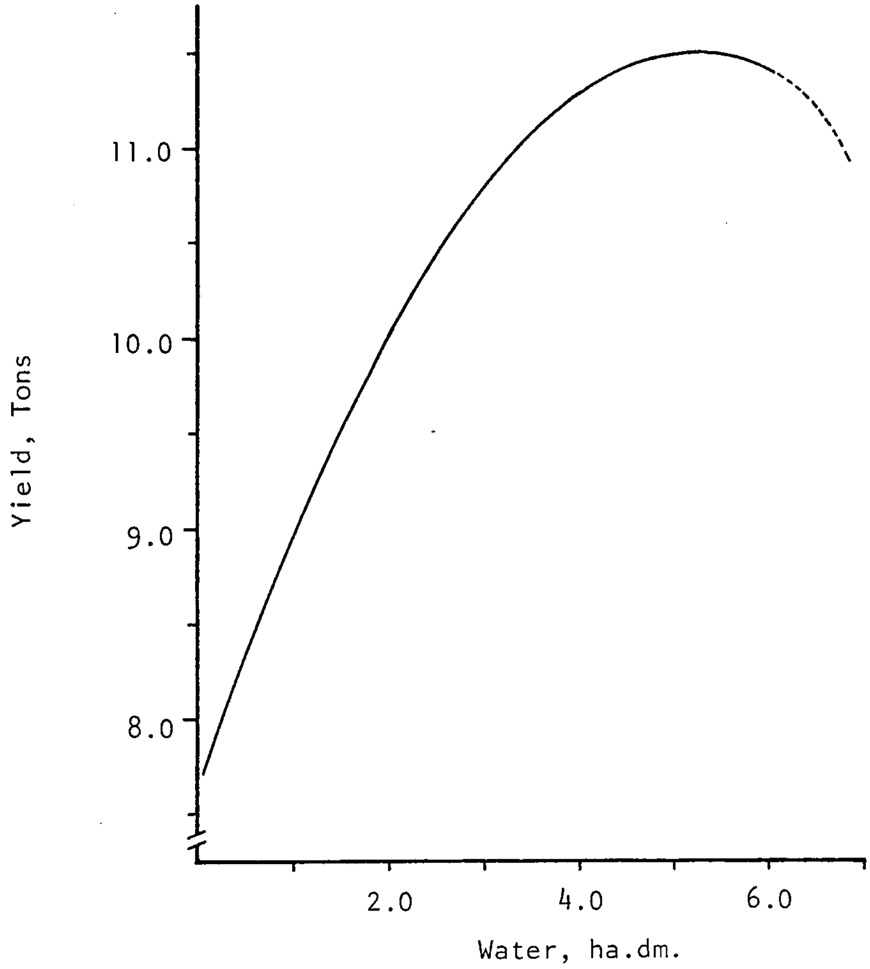

Figure 3. Total Water, Crop-Water Production Function[1] for Field Corn, Davis, California.

[1] Based on total water production function given in Table 4. Solid line indicates range of water data.

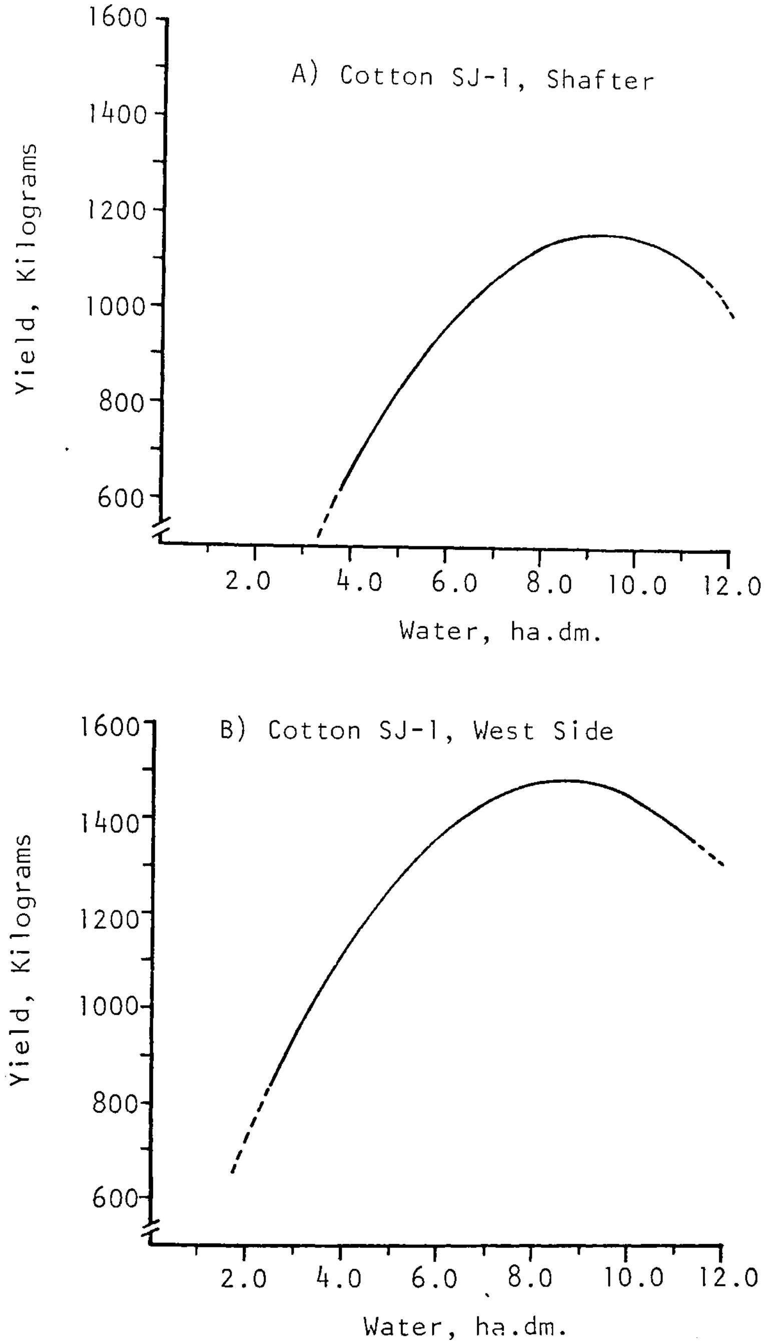

Figure 4. Crop-Water Production Functions [1] for Cotton, Acala SJ-1, Shafter and West Side, California.

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[1] Based on production functions given in Table 4. Solid line indicates range of water data.

The quadratic production function for Acala SJ-1 cotton at the West Side (Figure 4b) site explains 89% of the variation in yield ($\bar{R}^2 = .89$). Pan evaporation is included to differentiate between the two years of data used. The coefficient on the pan evaporation term is very significant although it does not have the expected sign. This is due to admittedly inaccurate measuring by the experimenters, and is the same sign as recorded by Heady and Hexem (1978) in their analysis using the same data, though they offer no explanation for it. All the other coefficients have the expected sign and all are significant at the 1% level.

The quadratic production function for Acala SJ-2 cotton at the West Side (Figure 5) site explains 97% of the variation in yield ($\bar{R}^2 = .97$). All the coefficients have the expected signs and are significant at the 1% level.

Tomatoes

The equation used to describe the relationship between yield and water applied for the UC-82 tomatoes is linear (Figure 6). Both the estimated constant and water applied coefficient are significant at the 1% level. The equation explains 69% of the variation in yield ($\bar{r}^2 = .69$).

The choice of a linear function can best be explained by looking at a graph of the original data points, yield versus water applied (Figure 7). Up to approximtely 2.0 dm. of applied water the yields are increasing as water applied increases.

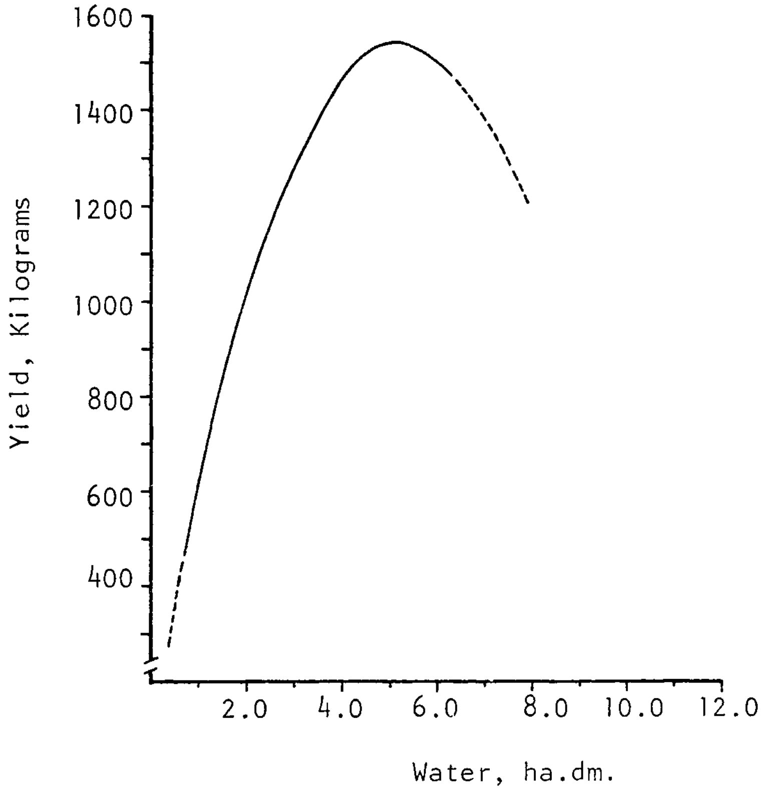

Figure 5. Crop-Water Production Function[1] for Cotton, Acala SJ-2, West Side, California.

[1] Based on production function given in Table 4. Solid line indicates range of water data.

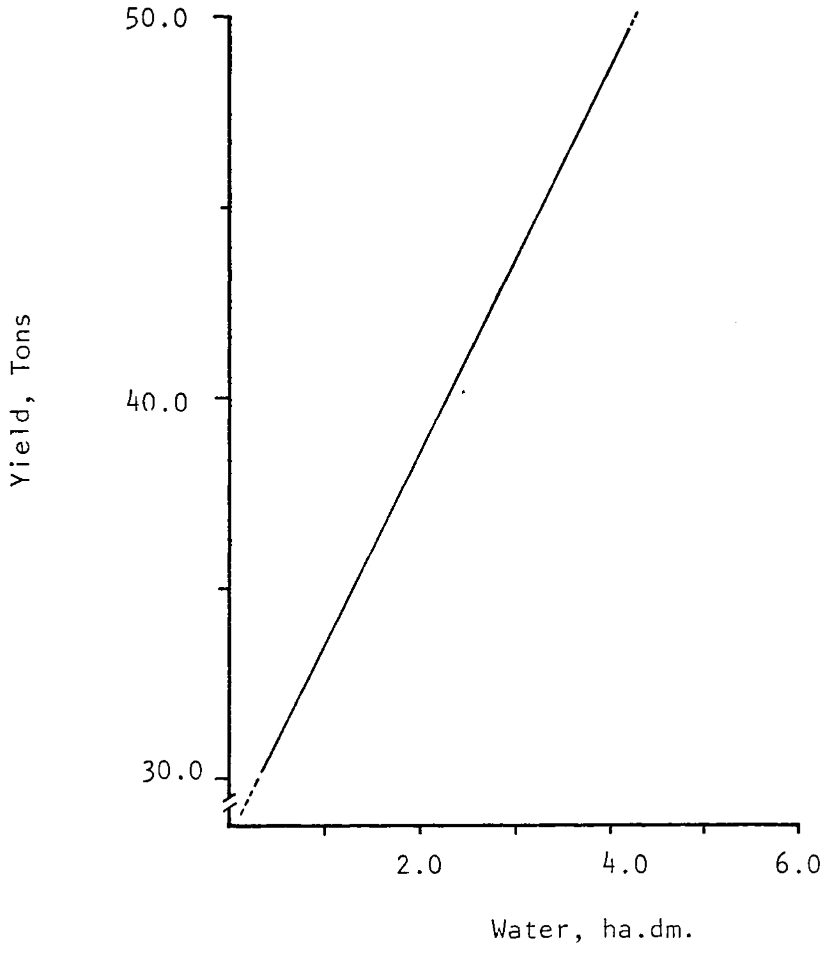

Figure 6. Crop-Water Production Function,[1] Processing Tomatoes, Davis, California.

[1] Based on production function given in Table 4. Solid line indicates range of water data.

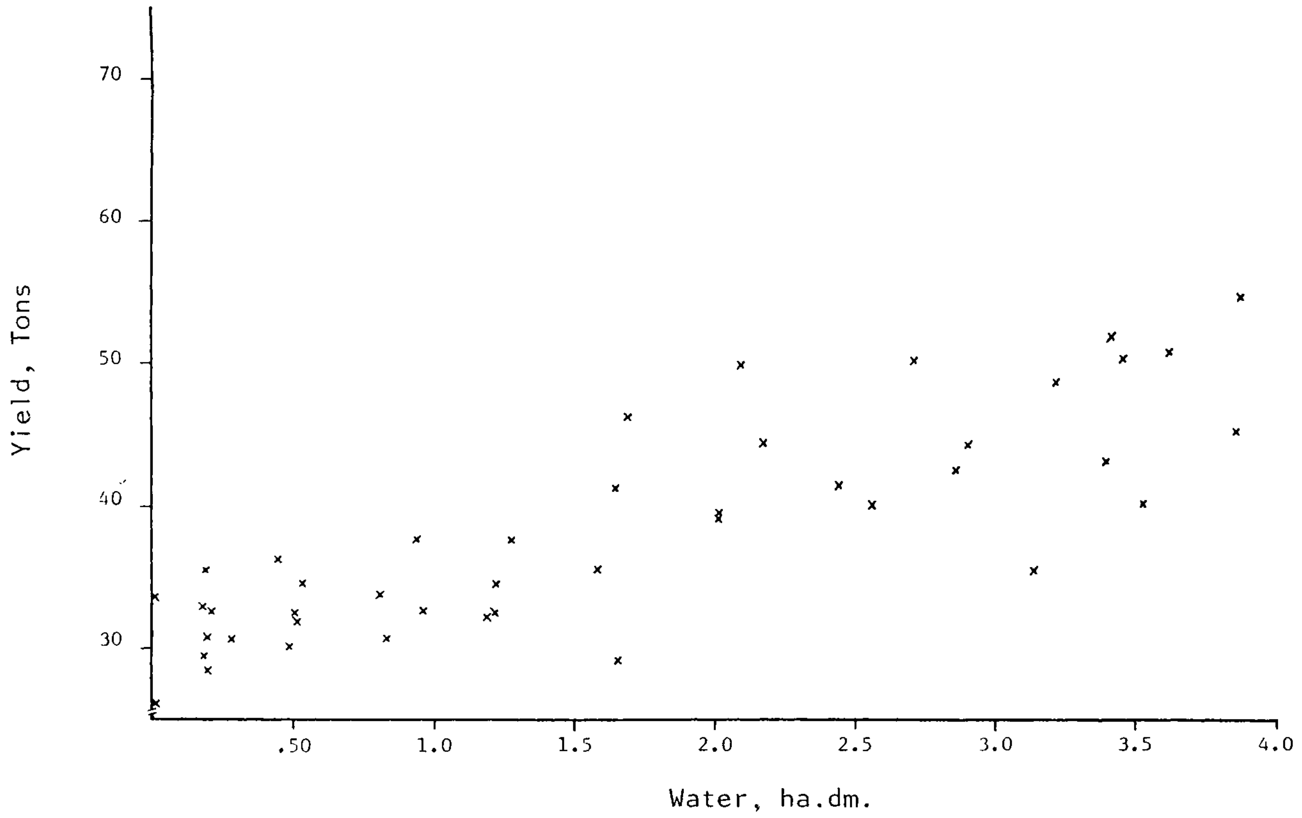

Figure 7. Processing Tomato Data.

After 2.0 dm. of applied water the relationship between yield and water applied is unclear.

The slope of a straight line fitted to data points beyond 2.0 dm. is statistically different from zero and indicates that more than 2.0 dm. of water should be used. How much more water should be used is indeterminate. A curvelinear line fitted to the data points beyond 2.0 dm. of applied water is not significantly different from zero. There is no indication from the set of data where diminishing returns to water begins. A straight line fitted to all the data points is therefore used to describe part of the yield versus water applied relationship. However, it is not reasonable to assume that yield will increase indefinitely as water applied increases. Therefore, the common practice level of irrigation, 3.35 ha.dm./ha. (Simms, 1981), for sprinkler irrigated UC-82 tomatoes is used here as the yield maximizing level of water.

CHAPTER 5

ECONOMIC ANALYSIS

Profit Maximizing Level of Irrigation Water

Profit maximizing levels of irrigation water are estimated from the production functions presented in Table 4. Three crop and water prices are used in each case to test the sensitivity of the functions to price. Rainfall is assumed to be 0, although in the areas studied it is often a small percentage (5-8%) of the total water applied.

Corn

Table 5 shows the profit maximizing level of irrigation water to be applied during each growth stage for corn given one of three product prices and one of three water prices. With a low price for water ($4.86/ha.dm.) there is very little difference in the profit maximizing level of water used in any growth stage regardless of corn price. As the price of water increases, however, the vegetative (V) and the maturation (M) stages show a greater sensitivity to the price increases than does the pollination (P) stage. The change in water application levels for the pollination stage is never more than .3 decimeter. The implication is that reductions in water applications during pollination have a greater effect on yield and thus profits than do reductions during other stages.

Table 5. Profit Maximizing Quantity of Water Computed from Growth Stages Production Function, with Varying Water and Product Prices, Field Corn, Davis, California.

Price of Water[2/] $/ha.dm.	V[3/]	Hectare Decimeters per Hectare[1/] P	M	Total
		Price Corn/metric ton-$88.00		
$ 4.86	2.33	1.64	2.13	6.09
24.32	1.96	1.49	1.74	5.19
48.64	1.51	1.30	1.25	4.06
		Price Corn/metric ton-$110.00		
$ 4.86	2.35	1.65	2.15	6.14
24.32	2.05	1.53	1.83	5.42
48.64	1.69	1.38	1.44	4.51
		Price Corn/metric ton-$154.00		
$ 4.86	2.37	1.66	2.17	6.19
24.32	2.16	1.57	1.94	5.67
48.64	1.90	1.46	1.67	5.03

[1/] 1 hectare decimeter is approximately 4 acre inches (1 dm. = 3.94 in.).

[2/] Conversions for water prices are:

$ 4.86/ha.dm. = $ .50/acre inch
$24.32/ha.dm. = $2.50/acre inch
$48.64/ha.dm. = $5.00/acre inch.

[3/] The three stages of plant growth are given by:

V = vegetative stage
P = pollination stage
M = maturation stage.

Other agronomic studies confirm these findings. The change in water applied in the vegetative stage ranges from .5 to .8 decimeter and in the maturation stage from .5 to .9 decimeter as water price increases. At the highest crop price a tenfold increase in the price of water results in a reduction in water application of .5 decimeter in the vegetative stage, .2 decimeter in the pollination stage, and .5 decimeter in the maturation stage, amounting to a seasonal reduction of 1.2 decimeters (a little over 4 inches).

Table 6 shows the profit maximizing level of water using the seasonal applied water production function. At the low water price there is very little change in the amount of water applied as crop price increases. At high crop prices, as the price of water increases tenfold the reduction in water applications is 1 decimeter (a little under 4 inches). In terms of total water applied for the season, comparison of the growth stage and the total water functions shows the growth stages equation to be slightly more sensitive to changes in water price than the total water applied equation. The growth stage change is 1.2 ha.dm. and the total water applied is 1.0 ha.dm.

Cotton

The profit maximizing levels of irrigation water for Acala SJ-1 cotton grown at Shafter and West Side are shown in Table 7. At low water prices very little change in water levels is shown for either location as the product price increases. At the high crop price the West Side cotton is slightly more sensitive to a tenfold increase in

Table 6. Profit Maximizing Quantity of Water Computed from Total Water Production Function, with Varying Water and Product Prices, Field Corn, Davis, California.

Price of Water $/ha.dm.	Price of Corn / metric ton $88	 $110	 $154
		Hectare Decimeters per Hectare	
$ 4.86	5.03	5.07	5.12
24.32	4.26	4.45	4.67
48.64	3.28	3.67	4.12

Table 7. Profit Maximizing Quantity of Water[1] with Varying Water and Product Prices, Cotton, Acala SJ-1 Shafter and West Side, and Acala SJ-2 West Side, California.

Price of Water	Price of Cotton[2]								
	Shafter SJ-1			West Side SJ-1			West Side SJ-2		
$/ha.dm.	$1.34	$1.76	$2.13	$1.34	$1.76	$2.13	$1.34	$1.76	$2.13
	Hectare Decimeters per Hectare								
$ 4.86	9.08	9.10	9.12	8.54	8.57	8.58	5.14	5.15	5.15
24.32	8.70	8.82	8.88	8.12	8.24	8.31	5.00	5.04	5.07
48.64	8.23	8.45	8.58	7.59	7.84	7.98	4.84	4.92	4.96

1/ Computed from production functions in Table 4.

2/ The price of cotton is the price of lint and seed per kilogram of lint.

water price; the change at West Side is .6 decimeter and the change at Shafter is .5 decimeter.

The profit maximizing levels of irrigation water for Acala SJ-2 cotton grown at West Side are shown in the last 3 columns of Table 7. The levels for the SJ-2 are on the average 3 decimeters (approx. 12 inches) below the profit maximizing levels for the SJ-1 variety. The lower water level is due primarily to a change from gravity irrigation used on the SJ-1 variety to sprinkler irrigation for the SJ-2 variety. The SJ-2 cotton is very insensitive to water price changes at any product price. At the highest product price a tenfold increase in water price produces only a .19 decimeter change in the water application level.

Comparison to Other Models

The profit maximizing water applications indicated by this study can be compared to levels indicated by other irrigation models. Only corn and gravity irrigated cotton models are available for comparison. For each crop the profit maximizing level is compared to the common practice level of area farmers, a yield maximizing level based on the production functions given earlier, and the water levels suggested by the experimenters, Stewart et al. (1977) for corn and Heady and Hexem (1978) for cotton.

Corn

Results of the corn comparisons are presented in Table 8. Water application levels have been broken into three stages of plant growth. The common practice model shows equal applications during each growth stage because farmers generally irrigate at the same level throughout the season (Horner, 1981). Stewart et al. (1977) recommend stressing the plant evenly throughout the growing season. For corn at Davis, California a water balance analysis based on the recommendations of Stewart et al. (1977) resulted in equal irrigations during each growth stage.

At the low water price (4.86/ha.dm.) the differences in the four models are not substantial except in the pollination stage. The level of water in the pollination stage for the profit and the yield maximization models is considerably lower than that of the common practice and Stewart models. The common practice level is high during the pollination stage because farmers generally do not differentiate among the growth stages when irrigating and apply water in equal irrigations. The Stewart model is high in the pollination stage because stressing the plant evenly throughout the growing season requires adequate irrigation during each growth stage to fill the soil profile. As the price of water increases the profit model level of water is considerably lower than the other three models in all stages. At the highest water price (48.64/ha.dm.) the difference between the common practice model and the profit model is great. The difference in water levels over all growth stages is 2.99 dm. or 12.2 inches.

Table 8. Water Application Levels Implied by Four Corn Models[1/]: Profit Maximizing Model, Common Practice, Yield Maximizing Model[2/] and Stewart, Hagan and Pruitt Model.

Price of Water $/ha.dm.		Profit Model	Common Practice	Yield Max Model	Stewart Hagan & Pruitt
		Hectare Decimeters per Hectare			
$ 4.86/ ha.dm.	V[3/]	2.35	2.42	2.42	2.02
	P	1.65	2.42	1.68	2.02
	M	2.15	2.42	2.22	2.02
$24.32/ ha.dm.	V	2.05	2.42	2.42	2.02
	P	1.53	2.42	1.68	2.02
	M	1.83	2.42	2.22	2.02
$48.64/ ha.dm.	V	1.69	2.42	2.42	2.02
	P	1.38	2.42	1.68	2.02
	M	1.44	2.42	2.22	2.02

[1/] Based on production functions in Table 4, Horner (1981), and Stewart et al. (1977).

[2/] In the profit maximizing model, the price of corn used is $110/metric ton.

[3/] The three stages of plant growth are given by:

V = vegetative stage
P = pollination stage
M = maturation stage.

Cotton

Results of the cotton comparisons are given in Table 9. The profit maximizing levels of water for gravity irrigated cotton indicated by this study are compared to common practice, yield maximizing, and the Heady and Hexem models. Common practice levels of irrigation are taken from Horner (1981). Yield maximizing levels are computed from the production functions in Table 4. The Heady and Hexem water levels are based on production functions presented in their book _Water Production Functions for Irrigated Agriculture_. The Heady and Hexem models are also profit maximizing models. The production functions on which they base their analysis, however, are a 1.5 polynominal for Shafter and a square root function for West Side rather than quadratics.

At Shafter the profit model shows lower levels of water applied at every water price than does any other model, though the Heady and Hexem model levels are not significantly higher. As the price of water increases the difference between the profit model water levels and both the common practice and yield maximizing levels increases to 2.25 dm. (8.9 inches) and .73 dm. (2.9 inches) respectively. Common practice levels are 1.5 dm. (approx. 6 inches) higher than yield maximizing levels. This may be attributed in part to higher field and delivery efficiencies at the experimental site than on the "average" farm in the Shafter area, to farmers' attitude toward risk, and to a lack of information on crop response to alternative levels of water.

Table 9. Water Application Levels Implied by Four Cotton Models:[1/] Profit Maximizing Model, Common Practice, Yield Maximizing Model and Heady and Hexem Model,[2/] Shafter and West Side, California.

Price of Water $/ha.dm.	Shafter				West Side			
	Profit Model	Common Practice	Yield Max Model	Heady and Hexem	Profit Model	Common Practice	Yield Max Model	Heady and Hexem
	Hectare Decimeters per Hectare							
$ 4.86	9.10	10.70	9.18	9.24	8.57	9.10	8.65	8.64
24.32	8.81	10.70	9.18	8.93	8.24	9.10	8.65	8.19
48.64	8.45	10.70	9.18	8.54	7.84	9.10	8.65	7.67

[1/] Based on production functions in Table 4, Horner (1981), and Heady and Hexem (1978).

[2/] In the profit maximizing and Heady and Hexem models Spring 1981 cotton prices are used (WSJ 4/3/81) - $1.76 for fiber and seed per kilogram of cotton fiber.

The results from West Side show that the profit maximizing model suggests lower levels of water application at all water price levels than do either common practice or yield maximizing models. At the low water price the profit model suggests .53 ha.dm. and .08 ha.dm. less than the common practice and the yield maximizing model respectively. At the high water price the profit model suggests 1.26 ha.dm. less (5 acre inches) and .81 ha.dm. less (3.2 acre inches) than the common practice and yield models respectively. The Heady and Hexem model suggests water levels which are not significantly different from the profit model levels.

The common practice levels of irrigation are higher, .45 dm. or approximately 2 inches, than the yield maximizing levels. At West Side the difference in profits per hectare between the two models is $22. Since the yield maximizing model gives only $22/ha. more profits, farmers may apply more water to avoid risking a low yield.

Effects on Water Pumped or Diverted, Water Applied, and Returns Over Total Variable Costs of Field and Delivery Efficiencies

Field Efficiency

Field efficiency, the ratio of water stored in the root zone to water delivered to the field, affects the profit maximizing level of water. The profit maximizing levels of water with varying field efficiencies are shown in Table 10. For furrow irrigated cotton, as field efficiency increases from .60 to .90 the amount of water applied decreases by 3.51 ha.dm. (13.82 acre inches) at Shafter and 3.27 ha.dm. (12.87 acre inches) at West Side, a 32% reduction at each site.

Table 10. Profit Maximizing Quantity of Water[1/] Applied with Varying Field Efficiencies for Cotton, Shafter and West Side, Tomatoes, Davis, and Corn, Davis, California.

Furrow Irrigation Efficiency	Cotton SJ-1 Shafter	Cotton SJ-1 West Side	Sprinkler Irrigation Efficiency	Cotton SJ-2 West Side	Tomatoes Davis	Corn Davis
	Hectare decimeters per hectare			Hectare decimeters per hectare		
.60	10.90	10.20	.75	6.35	4.24	6.56
.75	8.81	8.24	.85	5.62	3.74	5.94
.90	7.39	6.93	.95	5.04	3.35	5.42

1/ Based on Production Functions given in Table 4 with prices set at $24.32/ha.dm. for water and the medium product prices in Tables 5 and 7.

The sprinkler irrigated crops show smaller decreases in water applied as field efficiency increases. The change for cotton is 1.31 ha.dm. (5.16 acre inches) a 21% reduction, for tomatoes .89 ha.dm. (3.50 acre inches) a 21% reduction, and for corn 1.14 ha.dm. (4.49 acre inches) a 17% reduction.

The effects of various field efficiencies on returns over total variable costs (ROTVC) are shown in Table 11. ROTVC are affected in all cases. The gravity irrigated SJ-1 cotton at both Shafter and West Side shows a greater change in ROTVC as field efficiency increases than do any of the sprinkler irrigated crops. As efficiency increases from .60 to .90, ROTVC for SJ-1 cotton increase $122/ha. at Shafter, a 16% increase, and $114/ha. at West Side, an 8.5% increase. Increases in field efficiency for the sprinkler irrigated crops all show approximately a $50/ha. change in ROTVC as field efficiency increases from .75 to .95. The cost of improving field efficiency has not been included in the analysis and must be considered for a complete evaluation of improving field efficiency.

Delivery Efficiency

Delivery efficiency, the ratio of water reaching the field to water diverted or pumped, influences the amount of water which must be diverted or pumped in order for a given quantity to reach the field. Lower delivery efficiencies therefore imply higher costs per unit of water at the field.

Table 11. Returns Over Total Variable Costs[1] for Cotton, Tomatoes and Corn by Type of Irrigation for Varying Field Efficiencies[2].

Furrow	Cotton SJ-1		Sprinkler	Cotton SJ-2	Tomatoes	Corn
Irrigation Efficiency	Shafter	West Side	Irrigation Efficiency	West Side	Davis	Davis
	Dollars per hectare			Dollars per hectare		
.60	$758	$1,339	.75	$2,118	$2,156	$ 622
.75	831	1,407	.85	2,143	2,176	649
.90	880	1,453	.95	2,163	2,191	673

[1] Total Variable Costs include the cost of fertilizer, seed, pesticides, herbicides, fuel, labor and harvest costs (Horner, 1981).

[2] Based on Production Functions given in Table 4 with prices set at $24.32/ha.dm. for water and the medium product prices given in Tables 5 and 7.

The profit maximizing levels of water diverted or pumped and the levels applied at varying water prices and delivery efficiencies are shown in Table 12.

At the low water price, as delivery efficiency increases from .50 to .90 the amount of water diverted or pumped decreases by 7.95 ha.dm. (31.30 acre inches), a 44% decrease, at Shafter. At West Side the amount of water diverted or pumped decreases by 7.46 ha.dm. (29.37 acre inches), a 44% decrease.

At the high water price, as delivery efficiency increases from .50 to .90 the amount of water diverted or pumped decreases by 6.16 ha.dm. (24.3 acre inches), a 40% decrease, at Shafter. At West Side the amount of water diverted or pumped decreases by 5.45 ha.dm. (21.5 acre inches), a 39% decrease.

The effects of varying delivery efficiencies on returns over total variable costs for furrow irrigated cotton are shown in Table 13. At each water price, the delivery efficiency has a substantial effect on ROTVC per hectare. With a given efficiency, reading down the columns, increases in water prices have a considerable effect on ROTVC, and have an especially large impact at low delivery efficiencies. At the low efficiency, .50, as water price increases there is a decrease in ROTVC of $709/ha. at Shafter and $651/ha. at West Side.

As delivery efficiency increases, reading across the rows, ROTVC are again substantially affected at every water price. At high water prices, as delivery efficiency increases from .50 to .90 there is an increase in ROTVC of $507/ha. at Shafter and $371/ha. at West Side.

Table 12. Profit Maximizing Quantity of Water,[1] Diverted or Pumped and Quantity Applied with Varying Irrigation Delivery Efficiencies, Cotton, Acala SJ-1, Shafter and West Side, California.

Price of Water $/ha.dm.	Shafter			West Side		
	Hectare Decimeters per Hectare					
	Delivery Efficiency					
	.50	.75	.90	.50	.75	.90
	Hectare Decimeters Diverted or Pumped					
$ 4.86	18.06	12.11	10.11	16.97	11.38	9.51
24.32	16.91	11.60	9.75	15.68	10.81	9.11
48.64	15.46	10.95	9.30	14.06	10.09	8.61
	Hectare Decimeters Applied					
$ 4.86	9.03	9.08	9.10	8.48	8.54	8.56
24.32	8.45	8.69	8.77	7.84	8.12	8.20
48.64	7.73	8.21	8.37	7.03	7.57	7.75

[1] Based on Production Functions given in Table 4 and price of cotton set at $1.76 for fiber and seed per kilogram of cotton fiber.

Table 13. Returns Over Total Variable Costs[1/] for Furrow Irrigated Cotton[2/] with Varying Delivery Efficiencies, Shafter and West Side, California.

Price of Water $/ha.dm.	Shafter			West Side		
	Delivery Efficiency					
	.50	.75	.90	.50	.75	.90
	Dollars per Hectare					
$ 4.86	$ 874	$ 960	$ 989	$1466	$1527	$1554
24.32	545	734	799	1141	1316	1376
48.64	165	466	672	795	1069	1166

1/ Total Variable Costs include the costs of fertilizer, seed, pesticides, herbicides, fuel, labor, and harvest costs (Horner, 1981).

2/ The price of cotton is $1.76 for fiber and seed per kilogram of cotton fiber.

At the low water price, increases in delivery efficiency result in an increase in ROTVC of $115/ha. at Shafter and $108/ha. at West Side.

Effects on Profits of Reduction in Available Water

Restrictions on the amount of water that is available for farm use may be imposed for a variety of reasons. Governmental intervention to conserve water, or to reduce the amount of salt in return flows, droughts, or over use of a water supply in a given time period are some causes of restrictions. In California for example, state law requires the agricultural sector to take cuts in water during a drought before the urban sector.

The effects of restrictions on profits depend on the underlying crop-water production functions. Production functions which include water applied by plant growth stage indicate when water cuts would least affect yields and consequently profits. Production functions which do not include growth stage variables indicate the effects of reductions in water use on profits.

The effects on corn profits of a reduction in available water are shown in the first three columns of Table 14. The profit maximizing level of irrigation over the season was reduced by ten and twenty percent and the seasonal reduction was subtracted separately from each stage. Twenty percent reductions in the pollination stage have the greatest effect on profits. The estimates show that reductions occurring in either the vegetative or maturation stages have an almost equal effect on profits. With a 20% reduction in water there is a $27/ha. change in profits for the vegetative stage and a $25/ha. change in the

Table 14. Returns[1/] Over Total Variable Costs[2/] with Water Restrictions During Various Stages of Plant Growth, Field Corn, Davis, California.

Total Water Restricted During One Growth Stage (growth stage with reduction indicated by ↓)				Reduction from Profit Maximizing Level Occurring in Each Growth Stage
% Reduction	V↓	P↓	M↓	V↓ P↓ M↓
	Dollars per Hectare			
0	$673	$673	$673	$673
-10	668	654	669	673
-20	646	589	648	667

[1/] The price of corn is $110/metric ton.

[2/] The price of water is $24.32/ha.dm.

maturation stage. A 10% reduction in available water has little effect on profits regardless of the growth stage in which it occurs. The pollination stage is still the most sensitive to water restrictions, but the change in profits when water is restricted in the pollination stage is only $19/ha.

The effects on corn profits of reductions in water levels 10 and 20% below the profit maximizing level in each growth stage are shown in the last column of Table 14. With a 10% reduction occurring in all stages there is no change in profits. With a 20% reduction in water application levels occurring in all growth stages there is only a $6/ha. change in profits. These results confirm Stewart et al.'s contention that corn should be evenly stressed throughout the season.

The effects on profits of 10 and 20% reductions in seasonal available water for cotton SJ-1 and SJ-2, and processing tomatoes, are shown in Table 15. With a 20% reduction in available water the tomatoes and SJ-1 cotton grown at Shafter show a 10% reduction in profits, a change of $191/ha. for tomatoes and $88/ha. for cotton. The gravity irrigated SJ-1 cotton and the sprinkler irrigated SJ-2 cotton grown at West Side show a 4% reduction in profits when water is restricted to 20% below the profit maximizing level, a change of $66/ha. for the SJ-1 cotton and $88/ha. for the SJ-2 cotton.

Elasticity of Demand for Water In Irrigated Agriculture

The elasticity of demand for water at the field, given a field efficiency, is generally very low for the crops studied (Tables 16 and 17). Cotton has a more inelastic demand for water than corn.

Table 15. Returns Over Total Variable Costs with Water Restrictions Set at 0%, 10%, and 20% Below Profit Maximizing Level[1] for Cotton, Shafter and West Side, and Tomatoes[2], Davis, California.

Water	Cotton SJ-1		Cotton SJ-2	Tomatoes UC-82
Restrictions	Shafter	West Side	West Side	Davis
	Dollars per Hectare			
0	$831	$1407	$2163	$2191
-10%	814	1394	2144	2095
-20%	743	1341	2075	2000

[1] Based on Production Functions given in Table 4 and a water price of $24.32/ha.dm., a cotton price of $1.76 for fiber and seed per kilogram of cotton fiber and a tomato price of $64 per metric ton.

[2] Based on common practice levels.

Table 16. Point Elasticity of Demand for Water[1/] at the Field, by Growth Stage[2/] with Varying Crop and Water Prices, Field Corn, Davis, California.

Price of Water $/ha.dm.	V[3/]	P	M
		Price Corn/metric ton-$88.00	
$ 4.86	-.04	-.02	-.05
24.32	-.23	-.12	-.28
48.64	-.60	-.29	-.79
		Price Corn/metric ton-$110.00	
$ 4.86	-.03	-.01	-.04
24.32	-.18	-.10	-.21
48.64	-.43	-.22	-.54
		Price Corn/metric ton-$154.00	
$ 4.86	-.02	-.01	-.03
24.32	-.12	-.07	-.14
48.64	-.27	-.15	-.34

[1/] Computed from growth stages production function, Table 4.

[2/] The total elasticity of demand for water over growth stages will always be less than the largest elasticity of demand for any particular growth stage, given a water and corn price, for example, the total elasticity of demand for water given a water price of $48.64/ha.dm. and a corn price of $88.00/metric ton, is -.56.

[3/] The three stages of plant growth are given by:

V = vegetative stage
P = pollination stage
M = maturation stage.

Table 17. Point Elasticity of Demand for Water[1/] at the Field with Varying Crop and Water Prices, for Cotton, Shafter and West Side, California.

Price of Water	Shafter - Acala SJ-1			West Side - Acala SJ-1			West Side - Acala SJ-2		
	Cotton Price/kg			Cotton Price/kg			Cotton Price/kg		
$/ha.dm.	$1.34	$1.76	$2.13	$1.34	$1.76	$2.13	$1.34	$1.76	$2.13
$ 4.86	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.00	-.00
24.32	-.05	-.04	-.03	-.07	-.05	-.04	-.03	-.03	-.02
48.64	-.12	-.09	-.07	-.14	-.10	-.08	-.07	-.05	-.04

1/ Computed from production functions in Table 4.

At high water prices and low crop prices the elasticity for corn is close to -.6 while the elasticity for cotton is never more than -.14. Among the cotton sites and varieties, the sprinkler irrigated Acala SJ-2 grown at West Side has the most inelastic demand, -.004. For both corn and cotton, all locations, demand becomes more elastic as product prices decrease and water prices increase.

For both corn and cotton the elasticities are so low that marginal changes in the price of water will have little or no effect on the consumption of water, assuming there is no change in field or irrigation delivery efficiencies. For example, gravity irrigated Acala SJ-1 cotton grown at West Side at the medium product and water prices has an elasticity of demand of -.049. A one percent change in the price of water will result in a decrease in water use of only .049 percent. A ten percent change in the water price would result in a .49 percent change in water use. From Table 7 the profit maximizing level of water to be applied at West Side for cotton SJ-1 at medium product and water prices is 8.24 ha.dm. If the price of water increased ten percent from $24.32 per ha.dm. to 26.75 per ha.dm., water application levels would decline from 8.24 ha.dm. per hectare to 8.20 ha.dm. per hectare (approximately a .16 inch reduction per acre).

CHAPTER 6

IMPLICATIONS

The results of this study have implications for farm level irrigation management, government policies aimed at conserving water, and needed research.

Farm Level

At all water price levels profits can be marginally increased on gravity irrigated cotton by applying the profit maximizing levels of water rather than yield maximizing or common practice levels. As the price of water increases the increase in profits becomes more substantial. For sprinkler irrigated corn and cotton, profits can be marginally increased by cutting water application levels at medium and high water prices to profit maximizing levels. The increase in profits will not be as great as for gravity irrigated cotton.

For corn the analysis points out the importance of irrigation scheduling when water is a limiting factor. Corn profits are least affected when corn is stressed in the maturation and/or vegetative stages. Cutting irrigations in either or both of these stages has minimal effects on yields or profits. A 10% reduction in water applied during either the vegetative or maturation stage decreases profits by less than one percent and for a 20% decrease in water applied profits decrease by only 4%.

Water Conservation Policy

Throughout the state of California water could be conserved if farmers switched from the water application levels they are now using to profit maximizing levels. At high water prices ($48.64/ha.dm.) both the SJ-1 cotton and corn would use between 2.0 ha.dm. and 2.5 ha.dm. less per hectare (approximately 8 to 10 acre inches) if profit maximizing levels are used. Extension services could change the emphasis of its recommendations from water applications that maximize yields to water applications that maximize profits.

The analysis shows demand for water, given field and delivery efficiencies, to be very inelastic for all crops at all water and product prices examined. This implies that marginal changes in the price of water will do little to reduce demand for consumptive water use. In order for pricing policies alone to substantially influence the amount of water applied by farmers, given field and delivery efficiencies, very large changes in water prices must occur.

The analysis implies that water can be conserved, especially where crops are gravity irrigated, when field efficiency increases. Profit maximizing water application levels for gravity irrigated SJ-1 cotton decrease by 3.6 ha.dm. at Shafter and 3.2 ha.dm. at West Side as field efficiency increases from .60 to .90. The savings in water on a per hectare basis is substantial (3.6 dm. = 14.2 inches and 3.2 dm. = 12.6 inches).

The implications for governmental water conservation programs or policies aimed at increasing delivery efficiencies are similar to those for increasing field efficiency. Cost-sharing, tax credits or other governmental programs designed to encourage increasing delivery efficiency through lining canals or improving ditches may conserve substantial quantities of water. As delivery efficiency increases from .50 to .90, the decrease in the amount of water diverted or pumped on Acala SJ-1 cotton ranges from 5.5 dm. (21.7 inches) to 8 dm. (31.5 inches) depending on water price. As delivery efficiency increases, ROTVC also increase. The analysis presented here, however, does not include an estimation of the social costs and benefits of various programs to improve efficiencies. Only the return side has been examined.

The implications of a government program to restrict water use at 10% or 20% below the profit maximizing level are mixed. For corn, restrictions of up to 20% have little or no effect on farmer profits. The effects on profits of reductions below the common practice level for tomatoes is approximately a 10% reduction in profits for a 20% reduction in water. The effects of a 20% reduction in water below profit maximizing levels is again approximately a 10% reduction in profits per hectare for SJ-1 cotton grown at Shafter. Reductions at West Side for both SJ-1 and SJ-2 cotton 20% below profit maximizing levels of water result in a 4% reduction in profits per hectare.

Research

Agronomic experiments which vary irrigation levels during the different stages of plant growth are needed on more crops in more locations in order to replicate the analysis and obtain more generalizable implications.

A multi-crop economic analysis is needed. The crops analyzed in this study could be incorporated into a larger multi-crop analysis. Farmers make decisions for their farm as a whole rather than on a crop by crop basis, and therefore, the effects of various policies on water use, farm profits, and other factors should account for not only the factor-product, but also the product-product relationships.

Research is needed to show the costs and benefits of changing from one irrigation technology to another and of alternative government tax and subsidy programs to encourage the adoption of water-saving techniques.

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